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NAVHLTHRSCHC
REPORT NO. 79-28

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THE DIURNAL FUNCTION OF READING RATE, COMPREHENSION AND EFFICIENCY*

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* Report No. 79-28, supported by the Naval Medical Research and Development Command, under research work unit MR041.01.03-0152. The views presented are those of the author and are not to be construed as necessarily reflecting the official view or endorsement of the Department of the Navy.

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INTRODUCTION

The relationship between time-of-day, human performance on a variety of tasks, and certain physiological and arousal measures has been the subject of two texts edited by Colquhoun[2,3] and an extensive review by Conroy and Mills[5]. Most of the studies reported were performed in controlled laboratory settings. Synchrony between the rhythms of body temperature, arousal and performance over time has been demonstrated but a cause-effect relationship has not been established (Moses, Lubin, Naitoh and Johnson[12]; Rutenfranz, Aschoff and Mann[14]). These same measures have been shown to remain fairly stable during normal as well as altered sleep schedules and environments (Colquhoun[4]).

Although a large number of performance tests used in laboratories and school settings depend indirectly upon the subject's proficiency in reading and reading comprehension, these skills have not been studied directly for time-of-day effects. Reading is undisputably an important ability in any modern society.

This study was part of a larger research program on the circadian effects upon performance. The primary purpose was to investigate autorhythmometrically time-of-day effects upon the measures of reading rate and comprehension, describing the two functions and determining their relationship.

METHODS

Subjects and General Procedure

The subjects were 24 (11 female, 13 male) volunteers, aged 18-48, in presumed good health, employed full time in the local area and were either part-time evening college students or college graduates. Subjects were

aware of the purpose of the experiment and thoroughly trained in the procedures and the use of materials and test instruments.

Beginning at eyes-open time Monday morning (05^{30}-08^{35}), subjects started self-rating six times per day for five days throughout their usual awake time. Last measurements were taken Friday evening or early Saturday morning (21^{41}-03^{15}). Data were recorded in autorhythmometric booklets containing step-by-step procedures, subjective rating scales and reference instructions. Measurement sequences were to be spaced approximately three hours at the discretion of the subject. Once each day the subjects took one form of a standardized reading test. The first and earliest test session was on Monday, the last and latest was on Friday.

The subjects were visited twice each day by the experimenter. Diets, work-rest cycle, liquid intake or other personal habits such as smoking, coffee drinking, etc., were not curtailed except for excesses. Control was asserted over these factors 30 min prior to and during measurements as per Halberg, Johnson, Nelson, Runge and Sothern[9]. Subjects used the same locations at home and work for measurements throughout the week. All measurements were taken in a sitting position.

Measures

Oral temperature (OT) was measured sublingually (held 5 min) at the beginning of each measurement session using a Becton-Dickinson Basal Thermometer (95-100°F.) accurate to 1/10 degree. OT measures were followed by subjective measures of general activation (GA) (Thayer[16]) and a performance test of memory, called short-term memory (STM) by Halberg et al.[9] and Halberg[8]. For the week, 30 data points were obtained for each subject on each measure.

There are five standardized equivalent forms of the Miller Reading Efficiency Test[11] which can be self-administered.

Recall was measured immediately following a timed 10-min reading test session (TS). At most, 11 min may have elapsed from the moment of first exposure to the material and the requirement to recall it. Performance for each of five reading exercises was evaluated by Reading Rate (RR), Reading Comprehension (RC) and Reading Efficiency (RE) for each subject. RR (words read per minute) was determined by the line number completed at the end of 10 min. Comprehension was measured by a balanced proportion of recall and recognition items. The score is the ratio of the number correct to number tried multiplied by 100 to yield percent comprehended. The measure of RE is the product of rate times comprehension. Although efficiency is a compound measure, it may reflect a trade off between speed of reading performance and accuracy.

Analyses of Data

Subjects self-rated or measured in five groups beginning 1 Dec 1975 and ending 30 Jan 1976. Two male subjects dropped out, thus results are based upon an N=22. In this study, the measures of OT, GA and STM were included as documented baseline circadian measures. For each individual, a 24-h cosine curve was fit to the data by the non-orthogonal least-squares method. Group centroids summarized results across subjects. The significance of mean vectors was determined by Hotelling's T^2 and Rayleigh Z Test (Batschelet[1]).

The material for reading performance was considered insufficient for time-series analyses. Three univariate ANOVA repeated measures were conducted to determine time-of-day effects on the dependent measures of RR,

RC and RE. Friedman's two-way ANOVA (Siegel[15]) was used as a nonparametric test.

Within-subject Pearson correlations were performed for GA, OT and STM to determine the degree of relationship shown by these variables. A zero μ t-test was used to test the mean correlations for significance. Such a comparison was not possible for reading scores.

By calculating the between-subjects correlations within each test session, the time-of-day effect could be held constant. This procedure, fashioned after Rutenfranz et al.[14] and performed in our lab previously (Moses et al.[12]), would determine if the consistent relationship shown by the within-subject correlations was influenced primarily by mutual diurnal fluctuations or some independent effect. All variables could be subjected to this procedure, including reading performance measures.

RESULTS

The results of the frequency analysis for OT, GA and STM are shown in Tabs. 1 and 2. Significant circadian rhythms were found in each measure indicating that the highest temperatures, activation levels and memory performance were reached in the early to mid-afternoon. These results indicate that a subject's arousal level was highest during afternoon performance measures and that the memory function, as tested, followed rather closely the circadian rhythm of OT and GA.

Tab. 3 contains within-subject correlations for these same three variables. The mean within-subject correlations for OT, GA and STM were all significant indicating that, for an individual, the diurnal fluctuations for these variables showed consistent and similar patterns. Similarities in the shape of the distributions can be seen in Fig. 1.

Means for these variables were determined for those time frames when a reading test was accomplished.

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Tabs. 1, 2 & 3 and Fig. 1 about here

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Only 4 of the 65 between-subjects correlations holding time-of-day constant to remove the circadian influence were significant before correcting for multiple tests*. Applying the correction resulted in none of the correlations being significant. The tabled uncorrected critical ratio ($p < .05$) is .404. The significant correlations prior to correction were: TS1 (STM, RC); TS4 (GA, RC); TS5 (OT, STM) and (OT, GA).

The distribution and values for the reading scores from each test session are shown in Fig. 1. The results of ANOVA for reading scores indicated that scores across different times of day were significantly different for comprehension, $\underline{F}(4,84) = 4.05$, $p < .005$, and efficiency, $\underline{F}(4,84) = 3.35$, $p < .013$, but not for reading rate. When a conservative F test was applied, $\underline{F}(1,21)$, to correct for possible heterogeneity of covariance, these results were non-significant. The actual df correction factors were computed from the variance-covariance matrix. For comprehension the epsilon correction was 0.727 adjusting the df to 3 and 61, and for efficiency the epsilon was 0.623 for an adjusted df = 2 and 53. These results were confirmed by Friedman's two-way nonparametric analysis of variance (Siegel[15]). No difference was found between male and female subjects for reading measures. Considering the df correction, the null hypothesis can be rejected at the .05 level of confidence for RR and RC.

* Bonferroni multi-test procedure (Larzelere and Mulaik[13]).

An analysis for trend revealed a significant quadratic component in the data for comprehension, $F(1,21) = 9.93$, $p < .01$. The other components were non-significant. Individual comparisons, using Newman-Keuls procedure, showed that the results of test session 1 (mid-morning) and test session 5 (late night) were similar, and that there were no differences between the test sessions taken in the afternoon (TS 3 and 4) and early evening (TS 5). There were differences ($p < .05$) between sessions 1 and 2, 1 and 3, and 1 and 4. By comparing the collapsed mean of sessions 1 and 5 with the mean of sessions 2, 3 and 4, a significant difference was found ($t = -3.378$, $p < .01$). It was clear that reading comprehension was superior in the afternoon and early evening when compared to mid-morning and late night performance. Fig. 2 shows a distribution of errors committed by subjects as a function of time-of-day. The curve indicates that performance was probably less error prone during the afternoon than morning.

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Fig. 2 about here

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ANOVA did not reveal significant changes in reading rate over the day although there was a near linear decrease in reading performance. Further examination of RR performance was accomplished by use of Z scores. Each subject's raw score was converted to Z scores to remove the influence of individual differences in reading ability. All scores were then organized by time-of-day according to the actual time a subject took each reading test. A mean ($N \geq 5$) Z score was computed across subjects for each hour of the waking day. Fig. 3 presents a time-of-day distribution of mean Z

scores for RR. As can be seen, performance was shown to be above average in the morning hours (up to 14^{00} hours), becoming below average as the day wore on. Fig. 4 compares the distributions of RR and reading comprehension computed as a function of percent change for mean performance. The mid-morning performance for RR was 5.62% above average compared to 9.87 below average for reading comprehension. The overall difference was 15.49% contrasted with 2.45% difference late at night. The rate of change for either function was not stable across time nor similar. Arousal level appeared to affect both functions differently; i.e., RC similar to GA and OT whereas RR negatively related to those functions.

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Figs. 3 & 4 about here

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DISCUSSION

The results of the frequency analysis indicate that despite workday pressures, circadian influences upon behavior are significant. Oral temperature, memory and activation were all shown to have substantial 24-h cycles with peak phase times to be within minutes of those found in laboratory-controlled environments for the same measures (Jovonovich, Jovonovich, Kaiser and Luttmers[10]; Halberg[8]). Fröberg, Karlsson, Levi and Lidberg[7] found peak urinary adrenalin excretion at 13^{07}, 8 min later than GA measures found here. The correlational analysis substantiated the findings of Rutenfranz et al.[14] and Moses et al.[12] Oral temperature, general activation and medium load memory performance follow similar synchronous circadian patterns; however, knowing the value of one variable (i.e., oral temperature) may not be used to reliably predict an absolute

value of another such as memory performance at a particular time-of-day. It would appear that direction of change is the only prediction possible.

The design for obtaining reading data (each subject following a set sequential procedure) was predicated upon a convenient method for mass autorhythmic data collection. The question concerning the role of practice effects confounding any diurnal changes must be addressed. First it should be noted that RR progressively worsened over the day rather than improved, the best performance being the first two test sessions. Also, reading comprehension performance displayed a quadratic function, quite a different distribution than rate. Secondly, neither function was altered when the data were detrended. Since this study, reading tests were again used in a sleep deprivation study (to be reported elsewhere). The tests were administered at 15^{00} over 5 days. There were no differences between baseline and recovery days for either rate or comprehension for that time-frame. Performance on those measures remained stable. Rate was significantly slowed down after 44 h of sleep loss but comprehension was unaffected. Although not a complete explanation, it does appear that the rate at which one reads decreases over the day in spite of experience, and that fatigue does not affect the ability to comprehend.

The shape of the distributions of comprehension or accuracy and rate or speed indicates that the two functions are different, perhaps out of phase by several hours, and that the rate of change is not linear for either. Arousal level may have a different effect upon these functions, although this question must be addressed in another study. Overall efficiency was significantly different, indicating a trade-off between speed and accuracy resulting in maintenance of performance efficiency over

the day. These findings support Folkard's[6] contention that, while performance is task dependent, speed and accuracy measures may represent different diurnal components of performance with correspondingly different relationships to arousal level.

This study has also shown that the autorhythmometric process, when well planned and used with trained subjects, can yield reliable data which in this case replicated laboratory findings to within minutes for OT, STM and arousal.

SUMMARY

The time course of RR and RC, when examined autorhythmometrically, has shown diurnal functions distinctly different from each other. Reading rate appears to be faster in the morning hours, progressively decreasing over the day. Reading comprehension improved from a low morning point to mid-day peaks, falling again late at night much the same way as oral temperature. Reading efficiency is affected by performance in rate and comprehension. The function appears bimodal with a general shape similar to reading comprehension. The circadian rhythms of oral temperature, general activation and memory were found to be synchronous, all peaking mid-afternoon. Attempts to predict the values of either OT, GA, STM or reading performance from knowing the value of the other variable at a particular time were not successful. Holding time-of-day constant, thus removing the circadian effect, would only indicate direction of change. The fact that cause-effect relationships between these functions could not be established by this method may indicate that these functions operate somewhat independently.

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TABLE 1. Acrophase values for oral temperature, memory and general activation (95% CI) (Hotelling's T^2 method).

Variable	Peak time (CI) reference midnight	Amplitude (CI)	$\bar{r}^2$
OT	15^{27} (14^{24}-16^{37})	0.411 (0.306, 0.519)	.35
GA	12^{59} (12^{14}-13^{41})	0.830 (0.691, 0.969)	.43
STM	15^{10} (13^{07}-17^{23})	0.048 (0.023, 0.073)	.17

TABLE 2. Mean vector length, peak time and dispersion value for OT, GA and STM.

Variable	Length of Mean Vector	Mean Peak Time	Dispersion	Rayleigh Z
OT	0.862	15^{36}	2 h 30 sec	17.823 *
GA	0.953	12^{58}	1 h 10 min	21.817 *
STM	0.636	14^{54}	3 h 16 min	9.695 *

* Sig. at .001

TABLE 3. Mean within-subject correlations of oral temperature, memory and activation (N=24)

Measures	$\bar{r}$ (± Sr)	Sig. Level
OT, STM	.14 (.21)	.01
OT, GA	.25 (.29)	.001
STM, GA	.18 (.22)	.001

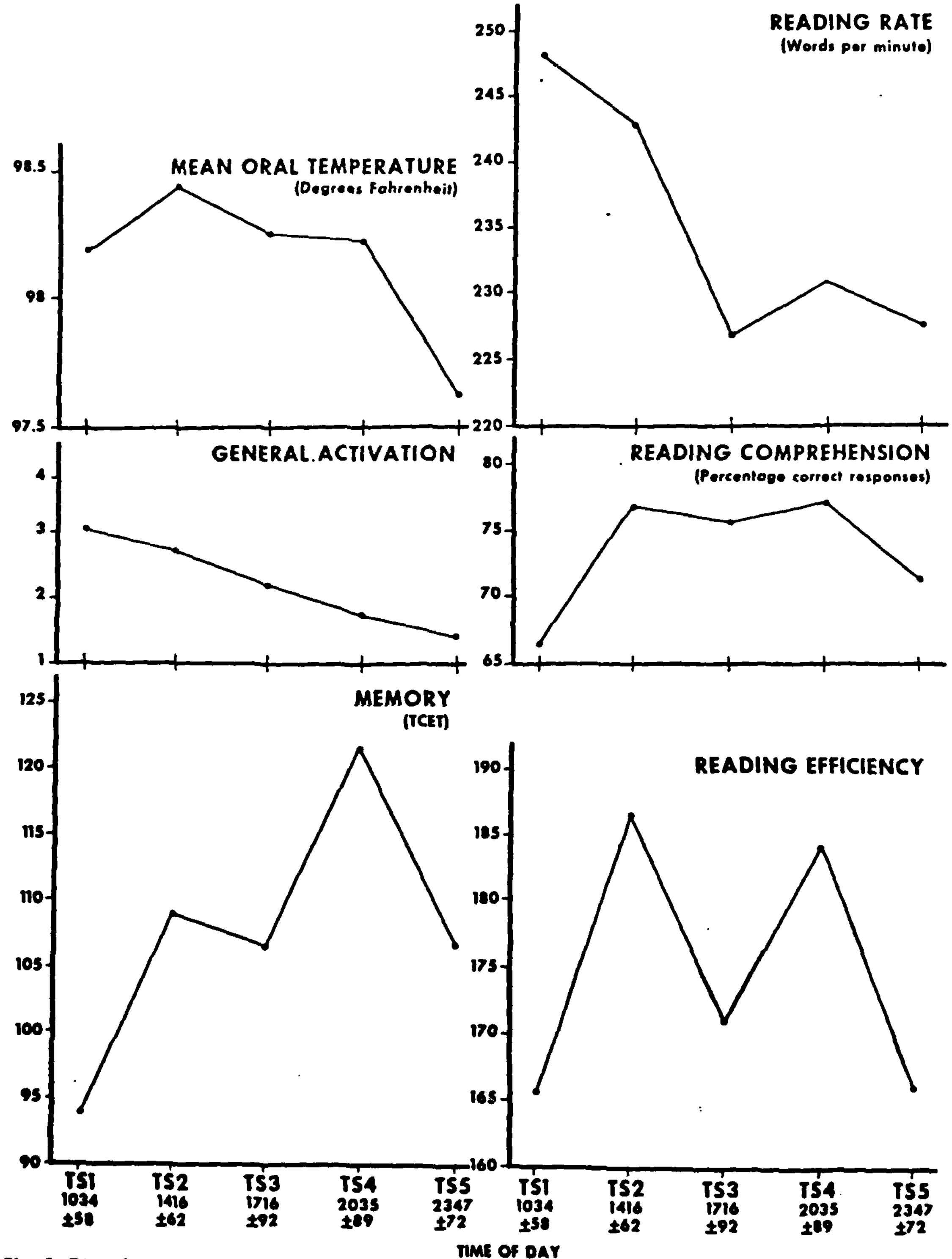

Fig. 1. Distribution of oral temperature, activation, memory and reading performance (N = 22)

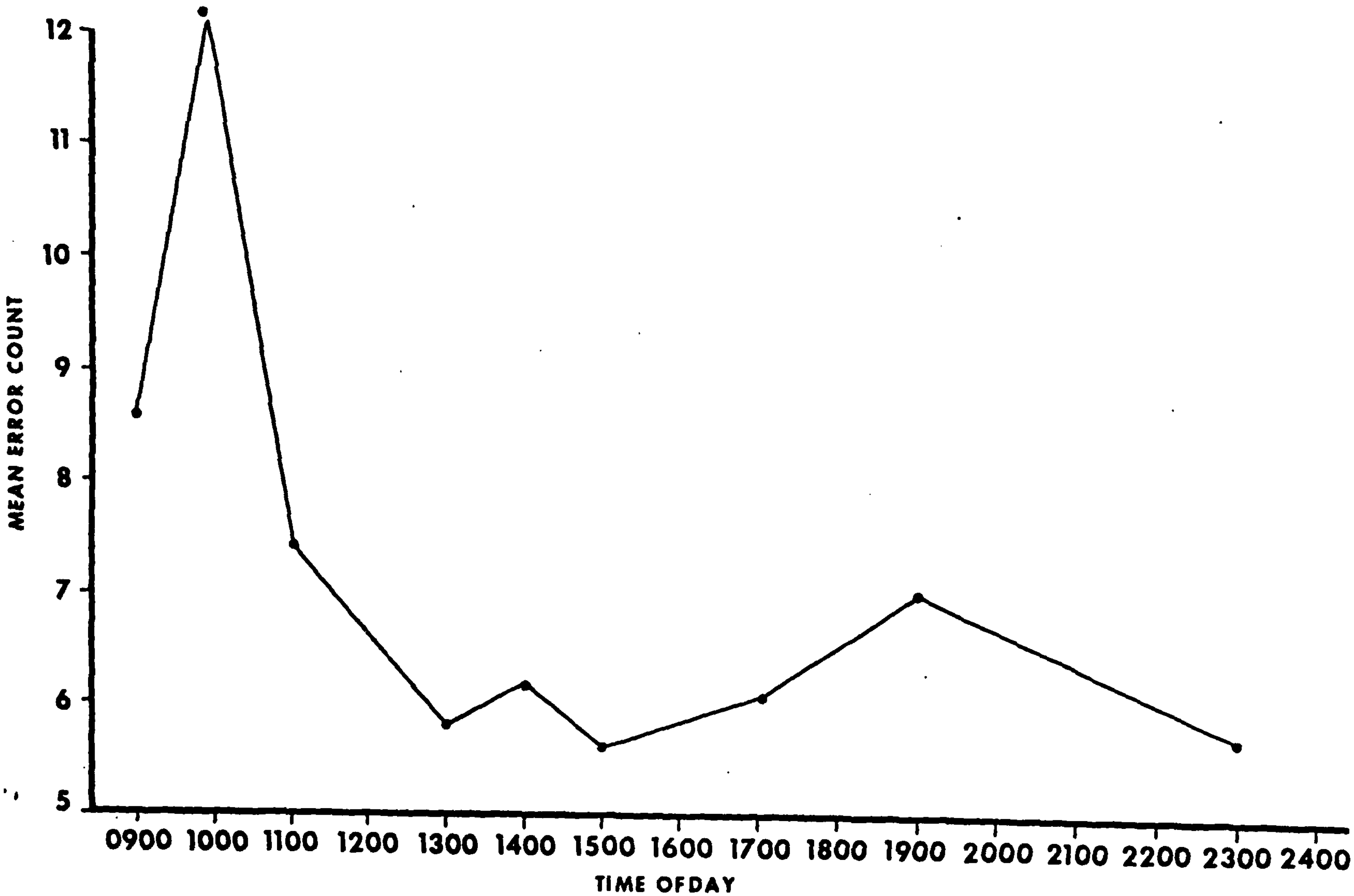

Fig. 2. Mean number of errors as a function of time of day

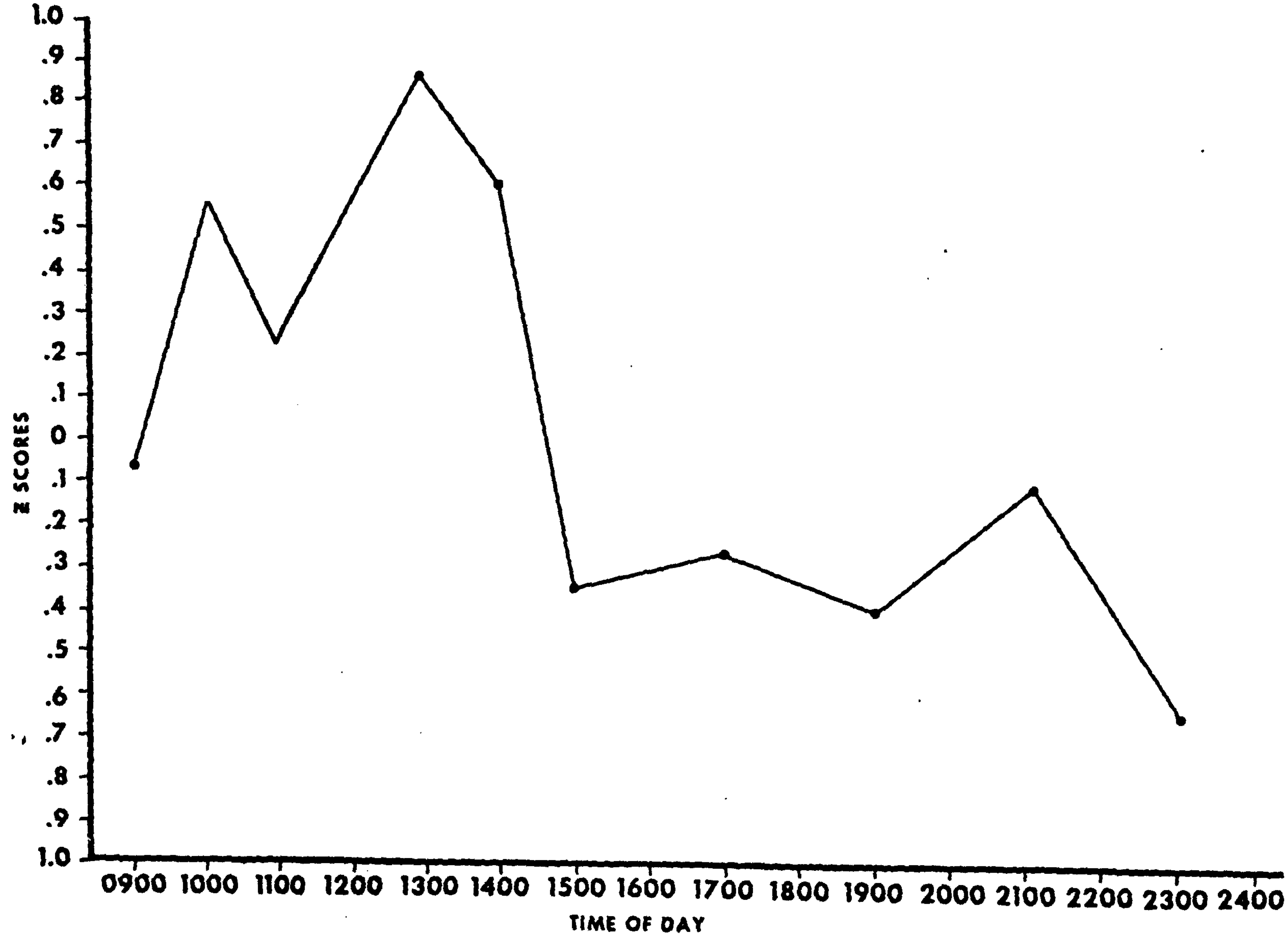

Fig. 3. Reading rate, mean Z scores by time of day across subjects

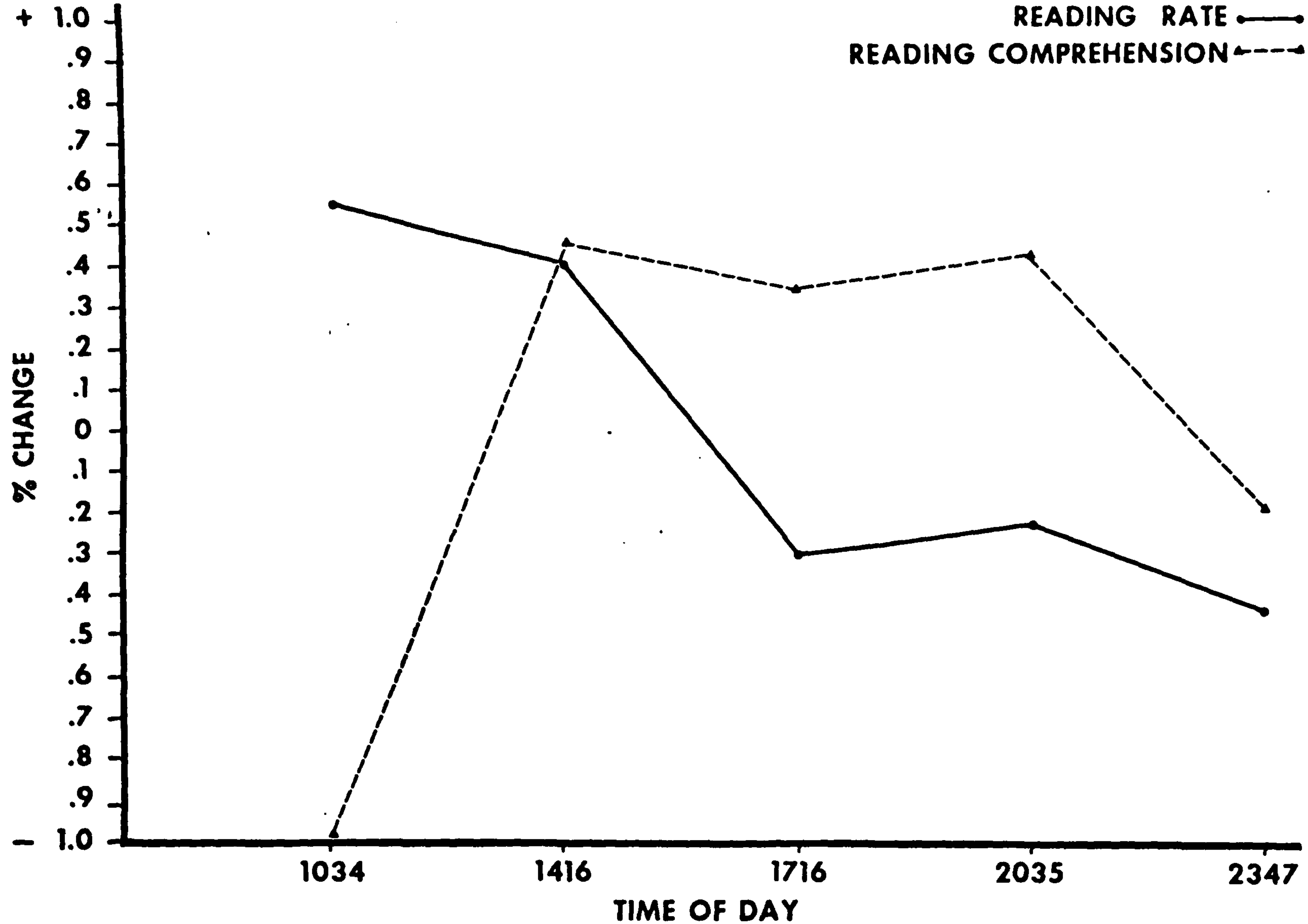

Fig. 4. Distribution of percentage change from mean performance of reading rate and comprehension (N = 22)

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 79-28	2. GOVT ACCESSION NO. AD A118118	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Diurnal Function of Reading Rate, Comprehension and Efficiency		5. TYPE OF REPORT & PERIOD COVERED Interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Carl E. Englund		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Health Research Center P. O. Box 85122 San Diego, CA 92138		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MR041.01.03-0152
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Medical Research & Development Command Bethesda, MD 20014		12. REPORT DATE July 1979
		13. NUMBER OF PAGES 17
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Bureau of Medicine & Surgery Department of the Navy Washington, D.C. 20372		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Circadian rhythm of body temperature and activation
Reading skills
Human
Autorhythmometry
Cosinor analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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